09-29-00

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PTO/SB/05 (12/97)
Approved for use through 09/30/00. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	**TI-29300**
First Named Inventor or Application Identifier	**Rustin W. Allred**
Title	**Digital Self-Adapting Graphic Equalizer and Method**
Express Mail Label No	EL552916241US

APPLICATION ELEMENTS

See MPEP Chapter 600 concerning utility patent application contents

ADDRESS TO: Assistant Commissioner for Patents, Box Patent Application, Washington, DC 20231

1. [X] *Fee Transmittal Form *(e.g., PTO/SB/17)* *(Submit an original, and a duplicate for fee processing)*
2. [X] Specification *(preferred arrangement set forth below)* [Total Pages 25]
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R&D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) *(35 USC d113)* [Total Sheets 3]
4. Oath or Declaration [Total Pages 3]
   - a. [X] Newly Executed (original or copy)
   - b. [ ] Copy from a prior application (37 CFR §1.63(d)) *(for continuation/divisional with Box 17 completed)*

   [Note Box 5 below]

   - i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR §1 63(d)(2) and 1 33(b).
5. [ ] Incorporation By Reference *(useable if Box 4b is checked)* The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. [ ] Microfiche Computer Program *(Appendix)*
7. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   - a. [ ] Computer Readable Copy
   - b. [ ] Paper Copy (identical to computer copy)
   - c. [ ] Statement verifying identical of above copies

ACCOMPANYING APPLICATION PARTS

8. [X] Assignment Papers (cover sheet & Documents(s))
9. [ ] 37 CFR §3 73(b) Statement *(when there is an assignee)* [ ] Power of Attorney
10. [ ] English Translation Document *(if applicable)*
11. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
12. [X] Preliminary Amendment
13. [X] Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
14. [ ] *Small Entity Statement(s) *(PTO/SB/09-12)* [ ] Statement filed in prior application Status still proper and desired
15. [ ] Certified Copy of Priority Document(s) *if foreign priority is claimed)*
16. [ ] Other

**A new statement is required to be entitled to pay small entity fees, except where one has been filed in a prior application and is being relied upon*

17. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information below and in a preliminary amendment:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No: /

Prior application information:* *Examiner ______ ***Group / Art Unit:*** ______

18. CORRESPONDENCE ADDRESS

[ ] *Customer Number or Bar Code Label* 23494 *(Insert Customer No. or Attach bar code label here)* or [X] *Correspondence address below*

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Name (Print/Type)	**Mark E. Courtney**	*Registration No. (Attorney/Agent)*	**36,491**
Signature	Mark E. Courtney	*Date*	9/28/00

FEE TRANSMITTAL

Patent fees are subject to annual revision on October 1.
These are the fees effective November 10, 1998
Small Entity payments must be supported by a small entity statement, otherwise large entity fees must be paid. See Forms PTO/SB/09-12.

TOTAL AMOUNT OF PAYMENT ($) 726

Complete If Known	
Application Number	
Filing Date	9/28/00
First Named Inventor	Rustin W. Allred
Examiner Name	TBD
Group / Art Unit	TBD
Attorney Docket No.	TI-29300

METHOD OF PAYMENT

1. ☒ The Commissioner is hereby authorized to charge to the following Deposit Account,

Deposit Account Number: 20-0668

Deposit Account Name: Texas Instruments Incorporated

☒ Charge any additional fee required or credit any overpayment

☐ Charge all indicated fees and any additional fee required or credit any overpayment

2. ☐ **Payment Enclosed:**

☐ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	760	201	380	Utility filing fee	690
106	310	206	155	Design filing fee	$
107	480	207	240	Plant filing fee	$
108	760	208	380	Reissue filing fee	$
114	150	214	75	Provisional filing fee	$

SUBTOTAL (1) ($)690

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	22	-20**=	2	x	18	=	36
Independent Claims	3	-3** =	0	x	78	=	0
Multiple Dependent					260	=	0

*** or number previously paid, if greater; For Reissue, see below*

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent Claims in excess of 3
104	260	204	130	Multiple dependent claims in excess of 3
109	78	209	39	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)36

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	380	216	190	Extension of time within second month	
117	870	217	435	Extension of time within third month	
118	1,360	218	680	Extension of time within fourth month	
128	1,850	228	925	Extension of time within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a pubic use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt.	
581	40	581	40	Recording each patent assignment per property (time number of properties)	
146	790	246	395	Filing a submission after final rejection (37 CFR 1 129(a))	
149	790	249	395	For each additional invention to be examined (37 CFR 1 129(b))	

Other fee (specify) ____________

Other fee (specify) ____________

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3)

SUBMITTED BY			Complete (if applicable)	
Typed or Printed Name	Mark E. Courtney		Reg. Number	36,491
Signature	Mark E. Courtney	Date 9/28/2000	Deposit Account User ID	

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

	Allred, et al.	Docket No.:	TI-29300
Serial No.:	TBD	Examiner:	TBD
Filed:	9/28/00	Art Unit:	TBD
For:	**Digital Self-Adapting Graphic Equalizer and Method**		

PRELIMINARY AMENDMENT

Honorable Assistant Commissioner

of Patents

Washington, D.C. 20231

"EXPRESS MAILING" Mailing Label No. EL552916241US

Date of Deposit September 28, 2000.

Please amend the above referenced Application as follows:

In the Specification:

Page 1, before line 1, insert --This application claims priority under 35 USC §119(e)(1) of provisional application number 60/169,519 filed 12/07/99.--

REMARKS

Entry of the foregoing amendment prior to examinations is respectfully requested.

If the Examiner has any questions or other correspondence regarding this application, Applicant requests that the Examiner contact Applicant's attorney at the below listed telephone number and address.

Respectfully submitted,

Mark E. Courtney
Attorney for Applicant
Reg. No. 36,491

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ATTORNEY DOCKET NUMBER
TI-29300P

PATENT APPLICATION

DIGITAL SELF-ADAPTING GRAPHIC EQUALIZER AND METHOD

TECHNICAL FIELD OF THE INVENTION

This invention is related in general to the field of digital signal processing. More particularly, the invention is related to digital self-adapting graphic equalizer and method.

RELATED PATENT APPLICATION

This application is related to co-pending U.S. Serial No.____________, entitled *digital graphic equalizer control system and method* (Attorney Docket No. TI-28878), filed on September 22. 1999.

BACKGROUND OF THE INVENTION

The acoustic sound generated by conventional speakers contains a large degree of distortion due to the physical limitations of the mechanical structure of the speakers. For purposes of this document, "distortion" is used to mean sound pressure level variation as a function of frequency. Therefore, even with high quality audio processing and digital recording, the actual acoustic sound waves reproduced by conventional speakers are typically far from an accurate reproduction of the original sound. In low end to mid-range electronic consumer products, the distortion due to the speaker system is even more pronounced.

Self-adapting speaker equalization systems are presently costly to implement. These conventional self-adapting speaker equalization systems are therefore unsuitable to low end to mid-range electronic consumer products, such as lap-top computers and desktop computers. However, the demand for high quality sound in these systems is unprecedented due to the proliferation of multimedia applications, digital music download and playback, and world wide web multimedia websites.

SUMMARY OF THE INVENTION

Accordingly, there is a need for digital self-adaptive graphic equalizer system and method which produces good sound quality and are not costly to realize and implement as conventional systems.

In one aspect of the invention, a self-adaptive graphic equalizer is operable to equalize the affects of an audio system on an audio signal. The self-adaptive graphic equalizer includes an adaptive graphic equalizer having a plurality of equalizing filters, where the plurality of equalizing filters have different center frequencies equidistant from one another and spanning a predetermined audio bandwidth. Each equalizing filter is operable to filter an i^{th} sub-band of the audio signal. A plurality of first filters are coupled to the audio system, each first filter is operable to filter an i^{th} sub-band of an output signal of the audio system. A plurality of second filters are operable to filter an i^{th} sub-band of the audio signal. A gain adjuster is operable to adjust the i^{th} sub-band of the adaptive graphic equalizer in response to a difference in the i^{th} sub-band of the filtered output signal from the plurality of first filters and the i^{th} sub-band of the filtered audio signal from the plurality of second filters.

In another aspect of the invention, a digital self-adaptive graphic equalization method that equalizes the affects of a speaker-microphone system and the environment on an audio signal includes the steps of receiving an output signal from the audio system, the output signal being generated by the audio system in response to the audio signal. The output signal is divided into N sub-bands and an i^{th} sub-band of the output signal is filtered, where i = 1-N. The audio signal is

also divided into the same N sub-bands and the i^{th} sub-band of the audio signal is filtered, where i = 1-N. A difference between the i^{th} filtered sub-band of the audio signal and the i^{th} filtered sub-band of the output signal is determined, and the gain of an i^{th} equalizing filter of an adaptive graphic equalizer is adjusted in response the difference between the i^{th} filtered sub-band of the audio and output signals. The equalizing filters have different center frequencies equidistant from one another and spanning a predetermined audio bandwidth. An equalized audio signal is generated and provided to the audio system.

In yet another aspect of the invention, a digital self-adaptive graphic equalization method that equalizes the affects of a speaker-microphone system and the environment on an audio signal includes the steps of receiving an output signal from the audio system, the output signal being generated by the audio system in response to the audio signal. The output signal is divided into N sub-bands and an i^{th} sub-band of the output signal is filtered, where i = 1-N. The audio signal is also divided into the same N sub-bands and the i^{th} sub-band of the audio signal is filtered, where i = 1-N. The method time averages the N sub-bands of the filtered output signal, time averages the N sub-bands of the filtered audio signal, and normalizes the time averaged N sub-bands of the filtered output signal and the time averaged N sub-bands of the filtered audio signal. A difference between the i^{th} filtered sub-band of the audio signal and the i^{th} filtered sub-band of the output signal is determined, and the gain of an i^{th} equalizing filter of an adaptive graphic equalizer is adjusted in response the difference between the i^{th} filtered sub-band of the audio

and output signals. The equalizing filters have different center frequencies equidistant from one another and spanning a predetermined audio bandwidth. An equalized audio signal is generated and provided to the audio system.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be made to the accompanying drawings, in which:

FIGURE 1 is a simplified block diagram of a conventional adaptive equalizer;

FIGURE 2 is a simplified block diagram of an embodiment of a self-adaptive digital graphic equalizer with multiple filters each operating on a sub-band of the audio band constructed according to the teachings of the present invention;

FIGURES 3A and 3B are frequency plots of the filter sub-bands and the graphic equalizer filter family, respectively according to an embodiment of the present invention;

FIGURE 4 is a simplified block diagram of an embodiment of the i^{th} band of self-adaptive digital graphic equalizer constructed according to an embodiment of the present invention; and

FIGURE 5 is a more detailed block diagram of an embodiment of an adaptive circuit and process of the self-adaptive digital graphic equalizer constructed according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGURE 1 is a simplified block diagram of a conventional adaptive equalizer 10. Digital self-adaptive graphic equalizer 10 receives an audio input signal 12, which is processed by an adaptive filter 14. The output from adaptive filter 14 is supplied to a speaker-microphone combination block 16. Speaker-microphone combination block 16 reproduces the audio signal processed by adaptive filter 14 and the acoustical sound output is measured by the microphone and provided as an acoustic input 18 to a summer 20. Summer 20 determines the difference between audio input 12 and acoustic input 18 and provides an adjustment input 22 to adaptive filter 14. Adjustment input 22 is used to adjust adaptive filter 14 to remove distortion introduced by the speaker, so that the difference between audio input signal 12 and the output from the speaker is minimized.

FIGURE 2 is a simplified block diagram of an embodiment of a self-adaptive digital graphic equalizer 30 with multiple filters each operating on a sub-band of the audio band constructed according to the teachings of the present invention. Self-adaptive digital graphic equalizer includes an adaptive graphic equalizer 34, which receives an audio input 32 and generates an output supplied to a speaker-microphone combination 36. The system can be pre-calibrated so that the unknown aspects of the performance are all due to the speaker and the play-back environment. For example, if the response of the microphone is not adequately flat, it can be pre-calibrated or equalized. If the microphone is relatively close to the speaker, the measured effects will be mostly due to the speaker itself, while the environment interaction becomes more apparent when the microphone is farther away from the speaker. Speaker-microphone

combination block 36 reproduces the audio signal processed by adaptive graphic equalizer 34 and the acoustical sound output is measured by the microphone and provided as an acoustic input to a filterbank 38. The output from filterbank 38 is provided to a summer 42. A second filterbank 40 filters the audio input 32 and also provides output to summer 42. Accordingly, the audio band of interest is divided into a plurality of sub-bands and filtered by filterbanks 38 and 40. Summer 42 determines the difference between the filtered audio input and the filtered acoustic input measured by the microphone and provides an adjustment input 44 to adaptive graphic equalizer 34. Adjustment input 44 is used to adjust adaptive graphic equalizer 34 to remove distortion introduced by the speaker, so that the difference between audio input signal 32 and the output from the speaker is minimized. FIGURE 3A contains frequency plots of a 10-band filterbank example, and FIGURE 3B is a frequency plot of the graphic equalizer filter family example according to an embodiment of the present invention. For the sake of clarity, FIGURES 3A and 3B provides only the outlines of ±18 dB filters with fixed center frequency/bandwidth value, or Q, and fixed spacing in log-frequency space. It may be noted that the range of the gain, the number of bands, the center frequencies, the spacing between filters, and the bandwidths, can be specified as desired for a particular application. Further, the spacing between the filters in each filter family and the center frequencies of the filter families need not be equidistant. The filter gains can be adjusted to the desired level within the specified range. Self-adaptive graphic equalizer 30 can be used to automatically approximate an inverse function for the speaker in its environment by using the difference between the outputs of the i^{th} filters in

filterbanks 38 and 40 to adjust the gain of the i^{th} filter in the graphic equalizer family.

FIGURE 4 is a simplified block diagram of an embodiment of the i^{th} band of self-adaptive digital graphic equalizer 30 constructed according to an embodiment of the present invention. Audio input signal 32 is received by an i^{th} band, G_i, 50 of graphic equalizer 34 (FIGURE 2), which produces an output that is then supplied to the speaker of speaker-microphone combination 36. The microphone measures the acoustic output of the speaker and provided as a measured acoustic input to an i^{th} band, R_i, 52 of filterbank 38 applied to the measured or received signal. Audio input 32 is supplied to an i^{th} band, O_i, 54 of filterbank 40 applied to the original audio input signal. Typically, R_i and O_i are identical filters. The i^{th} band 50 of adaptive graphic equalizer 34 receives an i^{th} adjustment signal from summer 56, which is the difference between the filtered output of R_i and O_i filters. Therefore, the i^{th} band of graphic equalizer 34 is adjusted according to the difference from summer 56.

FIGURE 5 is a more detailed block diagram of an embodiment of an adaptive circuit and process 60 of the self-adaptive digital graphic equalizer constructed according to an embodiment of the present invention. In an embodiment of the present invention, filterbank 52 includes bandpass filters R_1 to R_N 61-63, which each filter a sub-band of the measured acoustic output of the speaker. The output from filters R_{1-N} 61-63 are provided to low pass filters 65, LPF_{1-N} 66-68, which time average the R_{1-N} filter outputs. Filterbank 54 includes bandpass filters O_1 to O_N 90-92, which each filter a sub-band of the original audio input signal 32. The output from filters O_{1-N} 90-92 are provided to low pass filters 94, LPF_{1-N} 95-97, which time average the O_{1-N} filter outputs. Time averaging the filterbank outputs allows the

adaptation to be performed according to general trends rather than on instantaneous measurement values. Further, time averaging compensates for time delay differences between the two paths in the original audio signal and the measured acoustic output. The filtered original audio outputs, R_{Li}, are converted to dB space by 20 $\log_{10}$ circuits or algorithm 70-72. The filtered measured acoustic outputs, O_{Li}, are converted to dB space by 20 $\log_{10}$ circuits or algorithm 100-102. Accordingly,

$$r_{Li} = 20 \log_{10}(R_{Li}), \text{ and}$$
$$o_{Li} = 20 \log_{10}(O_{Li})$$

The dB values, r_{Li} and o_{Li}, are provided to a mean normalization circuit or algorithm 76, which normalizes the values to compensate for differences in scaling the two paths. Either r_{Li} or o_{Li} can be manipulated such that

$$\sum_i r_{Li} = \sum_i o_{Li}$$

by using summers 80-82 and 104-106. The mean-adjusted r_{Li} and o_{Li} are represented as r'_{Li} or o'_{Li}, which are then provided to less than comparison circuit or algorithm 110-112. In one embodiment of the present invention, if $r'_{Li} < o'_{Li}$, then the gain in G_i is incremented by a predetermined amount; if $r'_{Li} < o'_{Li}$ is not true, then the gain in G_i is decremented by a predetermined amount. Alternatively, the adjustment in the gain of the appropriate sub-band of graphic equalizer 50 may be accomplished by using the difference between r'_{Li} and o'_{Li} as the gain in dB which the i^{th} filter in the graphic equalizer is adjusted. As described in U.S. Application Serial No. ________, entitled *digital graphic equalizer control system and method* (Attorney Docket TI-28878), if the gain adjustment is not performed gradually, undesirable audible artifacts results. This embodiment

allows for gradual adjustments in the gain to avoid audible artifacts.

Also discussed in *digital graphic equalizer control system and method,* a frequency of gain update more than every 64 samples of the audio input signal is likely to introduce audible artifacts. Moreover, a listener may be able to discern gain adjustment when it is done too frequently. Therefore, the frequency of gain adjustment should be no more than once per 64 samples, and possibly even slower.

In implementing the present invention, many parameters may be varied and determined based on the specific implementation, such as the number of sub-bands, the orders of the filters, the match between the shapes of the filterbanks and the graphic equalizer filters, center frequencies, maximum ranges, etc. For example, the Q values of the filters may be different and the center frequencies may have spacing other than octave spacing. Therefore, the system designer has the flexibility to tune and adjust the circuit or algorithm according to the application at hand.

Although performance is improved in general when a large number of filters are used, a simplification of using only one bandpass filter each cycle yields good results. In one embodiment, the audio information is passed through R_1 and O_1 for a cycle, the filtered audio information is then used to adjust the gain of G_1. R_2 and O_2 would then be applied for the next cycle and the filtered information is then used to update the gain of G_2.

Furthermore, overall convergence of the system is improved when each filter is adjusted individually than when all the filters are adjusted simultaneously. In addition, due in part to the overlapping of the sub-bands, more rapid convergence is achieved when non-

adjacent sub-bands are adjusted simultaneously. Therefore in one embodiment, the full sets of bandpass filters in the filterbanks are applied, but the gain correction is only applied to one band each cycle. Further, the adjustment may be done for sub-band i = 1 one cycle, i = 2 the next cycle, and so forth. Alternatively, the sub-bands are adjusted by cycling through the sub-bands every other or every third sub-band, for example. If fewer than the total number of sub-bands will be adjusted in any one cycle, it is not necessary to actually implement the bandpass filters whose outputs are not needed. In digital systems, it is a simple matter to change the coefficients as needed, allowing only the particular bandpass filter(s) needed to be implemented.

In one embodiment, ten filter bands are used. The graphic equalizer filters are conventional second order bell-shaped equalizer filters with Q = 2. These filters are centered approximately at the frequencies of C's on the piano keyboard with two additional octaves added to cover the entire audio band: 32.7, 65.4, 130.8, 261.6, 523.3, 1046.5, 2093.0, 4186.0, 8372.0, and 16744.0 Hertz. The bandpass filters in both filterbanks may be second order Butterworth filters designed to be centered at the same frequencies as the corresponding graphic equalizer filters. As described in co-pending application *digital graphic equalizer control system and method,* rather than changing the equalizing filter coefficients such that the filter gains change in uniform steps on a dB plot, the coefficients may be changed such that the filter gains change in uniform steps on a linear plot. In this manner, when the equalizing filter is at a high gain setting, the gain is changed in very small and gradual increments to avoid generating audible artifacts. As the gain decreases, it becomes possible to change the gain in

larger steps and yet still remain artifact free. In other words, by changing the coefficients such that the gain changes linearly, as opposed to logarithmically as in the traditional dB scale, artifacts would be eliminated. For example, 128 filters equally spaced in linear (gain) space between +/- 18 dB may be used. In this example, the linear spacing between the filters is approximately 0.0611.

The time-averaging lowpass filters may also be implemented in a variety of ways, including computing a simple running average. Alternatively, a simple alpha filter

$$y(n) = \alpha x(n) + (1-\alpha) y(n-1)$$

with $\alpha = 2^{-11}$ may be used, for example.

As discussed in U.S. Patent Serial No. ________,.entitled *digital Audio Dynamic Range Compressor and Method*, (Attorney Docket TI-26912), the 20 $\log_{10}$ operation may be substituted by a base 2 logarithmic operation, which allows simple estimates. Therefore, the conversion to dB space may be performed by or replaced with base 2 logarithm estimates.

In operation, the graphic equalizer filter gains adjust over time and improves the performance of the system. Alternatively, the system may be pre-calibrated by first processing a white noise signal as input, to allow the filters to converge prior to operating on the actual audio signals. Thereafter, the graphic equalizer filter gains can be fixed or allowed to continue to adapt.

According to teachings of the present invention, the division of the audio band into various sub-bands may be extended beyond speaker equalization and be applied to a general inverse filtering problem, where an unknown system alters the audio signal. The present invention

may be implemented to pass the altered signal through a filterbank of N filters and adjust the gain of the corresponding sub-band of the graphic equalizer according to a difference between the same sub-band of the filtered input signal. Furthermore, although the present invention is shown and described as being applied to a single channel, a multi-channel system would similarly benefit from the application of the present invention.

Although several embodiments of the present invention and its advantages have been described in detail, it should be understood that mutations, changes, substitutions, transformations, modifications, variations, and alterations can be made therein without departing from the teachings of the present invention; the spirit and scope of the invention being set forth by the appended claims.

WHAT IS CLAIMED IS:

1. A self-adaptive graphic equalizer operable to equalize the affects of an audio system on an audio signal, comprising:

an adaptive graphic equalizer having a plurality of equalizing filters, the plurality of equalizing filters having different center frequencies and spanning a predetermined audio bandwidth, each equalizing filter being operable to filter an i^{th} sub-band of the audio signal;

a plurality of first filters coupled to the audio system, each first filter being operable to filter an i^{th} sub-band of an output signal of the audio system;

a plurality of second filters receiving the audio signal, each second filter being operable to filter an i^{th} sub-band of the audio signal; and

a gain adjuster operable to adjust the i^{th} sub-band of the adaptive graphic equalizer in response to a difference in the i^{th} sub-band of the filtered output signal from the plurality of first filters and the i^{th} sub-band of the filtered audio signal from the plurality of second filters.

2. The self-adaptive graphic equalizer, as set forth in claim 1, further comprising:

a first plurality of lowpass filters, each lowpass filter being operable to filter an i^{th} sub-band of the filtered audio signal;

a second plurality of lowpass filters, each lowpass filter being operable to filter an i^{th} sub-band of the filtered output signal;

a mean normalization circuit operable to normalize the i^{th} sub-band lowpass filtered audio signals and the the i^{th} sub-band lowpass filtered output signal and generate an i^{th} sub-band of mean-normalized audio signal and an i^{th} sub-band of mean-normalized output signals.

3. The self-adaptive graphic equalizer, as set forth in claim 2, further comprising:

a comparator coupled to the mean normalization circuit and operable to determine whether the i^{th} sub-band lowpass filtered output signal is less than the i^{th} sub-band of mean-normalized audio signal; and

the gain adjuster of the i^{th} sub-band of the graphic equalizer operable to increment or decrement the gain of the i^{th} sub-band of the graphic equalizer in response to the comparator comparison.

4. The self-adaptive graphic equalizer, as set forth in claim 2, further comprising:

a difference circuit coupled to the mean normalization circuit and operable to determine the difference between the i^{th} sub-band lowpass filtered output signal and the i^{th} sub-band of mean-normalized audio signal; and

the gain adjuster of the i^{th} sub-band of the graphic equalizer operable to add or subtract the difference from the gain of the i^{th} sub-band of the graphic equalizer.

5. The self-adaptive graphic equalizer, as set forth in claim 1, further comprising:

a time averaging circuit coupled to the plurality of first filters and the plurality of second filters and operable to compute time averages of the plurality of filtered output signals and the plurality of filtered audio signals;

a dB converter coupled to the time averaging circuit operable to convert the time averaged plurality of filtered output signals and the time averaged plurality of filtered audio signals to dB space; and

a normalization circuit receiving the time averaged plurality of filtered output signals and the time averaged plurality of filtered audio signals in dB space, and adjusting the signals so that:

$$\sum_i r_{Li} = \sum_i o_{Li}$$

where r_{Li} is the time averaged i^{th} filtered output signal in dB space, and o_{Li} is the time averaged i^{th} filtered audio signal in dB space.

6. The self-adaptive graphic equalizer, as set forth in claim 1, wherein the adaptive graphic equalizer comprises ten overlapping sub-bands, each sub-band having filters between ±18 dB.

7. The self-adaptive graphic equalizer, as set forth in claim 1, wherein the plurality of first and second filters each comprises bandpass filters.

8. The self-adaptive graphic equalizer, as set forth in claim 1, wherein the audio system is a speaker-microphone combination system.

9. A digital self-adaptive graphic equalization method to equalize the affects of an audio system on an audio signal, comprising:

receiving an output signal from the audio system, the output signal being generated by the audio system in response to the audio signal;

dividing the output signal into N sub-bands and filtering an i^{th} sub-band of the output signal, where i = 1-N;

dividing the audio signal into the same N sub-bands and filtering an i^{th} sub-band of the audio signal, where i = 1-N;

determining a difference between the i^{th} filtered sub-band of the audio signal and the i^{th} filtered sub-band of the output signal;

adjusting the gain of an i^{th} equalizing filter of an adaptive graphic equalizer in response the difference between the i^{th} filtered sub-band of the audio and output signals, the equalizing filters having different center frequencies and spanning a predetermined audio bandwidth; and

generating an equalized audio signal and providing the equalized audio signal to the audio system.

10. The self-adaptive graphic equalization method, as set forth in claim 9, further comprising:

lowpass filtering an i^{th} sub-band of the filtered audio signal, where i = 1-N;

lowpass filtering an i^{th} sub-band of the filtered output signal, where i = 1-N;

mean normalizing the i^{th} sub-band lowpass filtered audio signals and the i^{th} sub-band lowpass filtered output signal and generating an i^{th} sub-band of mean-normalized audio signal and an i^{th} sub-band of mean-normalized output signals.

11. The self-adaptive graphic equalization method, as set forth in claim 10, further comprising:

comparing the i^{th} sub-band lowpass filtered output signal with the i^{th} sub-band of mean-normalized audio signal; and

adjusting the i^{th} sub-band of the graphic equalizer in response to the comparison.

12. The self-adaptive graphic equalization method, as set forth in claim 10, further comprising:

comparing the i^{th} sub-band lowpass filtered output signal with the i^{th} sub-band of mean-normalized audio signal; and

incrementing the i^{th} sub-band of the graphic equalizer in response to the i^{th} sub-band lowpass filtered output signal being less than the i^{th} sub-band of mean-normalized audio signal, or decrementing the i^{th} sub-band of the graphic equalizer in response to the i^{th} sub-band lowpass filtered output signal being greater than the i^{th} sub-band of mean-normalized audio signal.

13. The self-adaptive graphic equalization method, as set forth in claim 10, further comprising:

determining a difference between the i^{th} sub-band lowpass filtered output signal and the i^{th} sub-band of mean-normalized audio signal; and

adjusting the i^{th} sub-band of the graphic equalizer by the amount of the determined difference.

14. The self-adaptive graphic equalization method, as set forth in claim 9, further comprising:

computing a time averages of the plurality of filtered output signals and the plurality of filtered audio signals;

converting the time averaged plurality of filtered output signals and the time averaged plurality of filtered audio signals to dB space; and

adjusting the time averaged plurality of filtered output signals and the time averaged plurality of filtered audio signals in dB space so that:

$$\sum_i r_{Li} = \sum_i o_{Li}$$

where r_{Li} is the time averaged i^{th} filtered output signal in dB space, and o_{Li} is the time averaged i^{th} filtered audio signal in dB space.

15. The self-adaptive graphic equalization method, as set forth in claim 9, wherein filtering the plurality of audio and output signals comprises bandpass filtering the plurality of audio and output signals .

16. The self-adaptive graphic equalization method, as set forth in claim 9, further comprising:

generating sound from the equalized audio signal using a speaker; and

measuring the generated sound using a microphone.

17. The digital self-adaptive graphic equalization method, as set forth in claim 9, wherein adjusting the gain of an i^{th} equalizing filter comprises incrementing i from 1 through N.

18. A digital self-adaptive graphic equalization method to equalize the affects of a speaker-microphone system and the environment on an audio signal, comprising:

receiving an output signal from the audio system, the output signal being generated by the audio system in response to the audio signal;

dividing the output signal into N sub-bands and filtering an i^{th} sub-band of the output signal, where i = 1-N;

dividing the audio signal into the same N sub-bands and filtering an i^{th} sub-band of the audio signal, where i = 1-N;

time averaging the N sub-bands of the filtered output signal;

time averaging the N sub-bands of the filtered audio signal;

normalizing the time averaged N sub-bands of the filtered output signal and the time averaged N sub-bands of the filtered audio signal;

determining a difference between the i^{th} filtered sub-band of the audio signal and the i^{th} filtered sub-band of the output signal;

adjusting the gain of an i^{th} equalizing filter of an adaptive graphic equalizer in response the difference between the i^{th} filtered sub-band of the audio and output signals, the equalizing filters having different center frequencies and spanning a predetermined audio bandwidth; and

generating an equalized audio signal and providing the equalized audio signal to the audio system.

19. The self-adaptive graphic equalization method, as set forth in claim 18, wherein time averaging the N sub-bands of the filtered audio signal and the filtered output signal comprises:

lowpass filtering the i^{th} sub-band of the filtered audio signal, where i = 1-N; and

lowpass filtering the i^{th} sub-band of the filtered output signal, where i = 1-N.

20. The self-adaptive graphic equalization method, as set forth in claim 18, wherein adjusting the gain of the graphic equalizing filter comprises incrementing the i^{th} sub-band of the graphic equalizer in response to the i^{th} sub-band lowpass filtered output signal being less than the i^{th} sub-band of mean-normalized audio signal, or decrementing the i^{th} sub-band of the graphic equalizer in response to the i^{th} sub-band lowpass filtered output signal being greater than the i^{th} sub-band of mean-normalized audio signal.

21. The self-adaptive graphic equalization method, as set forth in claim 18, wherein adjusting the gain of the graphic equalizing filter comprises adjusting the i^{th} sub-band of the graphic equalizer by the amount of the determined difference.

22. The self-adaptive graphic equalization method, as set forth in claim 18, further comprising:

generating sound from the equalized audio signal using a speaker; and

measuring the generated sound using a microphone.

DIGITAL SELF-ADAPTING GRAPHIC EQUALIZER AND METHOD

ABSTRACT OF THE DISCLOSURE

A self-adaptive graphic equalizer operable to equalize the affects of an audio system on an audio signal includes an adaptive graphic equalizer having a plurality of equalizing filters, where the plurality of equalizing filters have different center frequencies equidistant from one another and spanning a predetermined audio bandwidth. Each equalizing filter is operable to filter an i^{th} sub-band of the audio signal. A plurality of first filters are coupled to the audio system, each first filter is operable to filter an i^{th} sub-band of an output signal of the audio system. A plurality of second filters are operable to filter an i^{th} sub-band of the audio signal. A gain adjuster is operable to adjust the i^{th} sub-band of the adaptive graphic equalizer in response to a difference in the i^{th} sub-band of the filtered output signal from the plurality of first filters and the i^{th} sub-band of the filtered audio signal from the plurality of second filters.

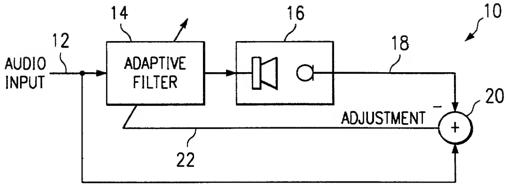


FIG. 1

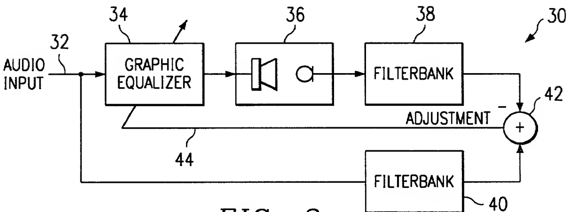


FIG. 2

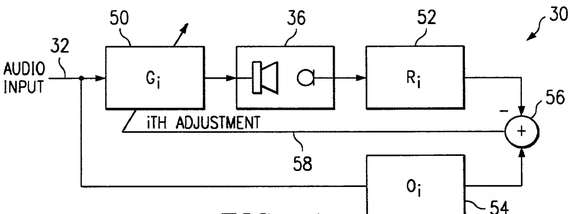


FIG. 4

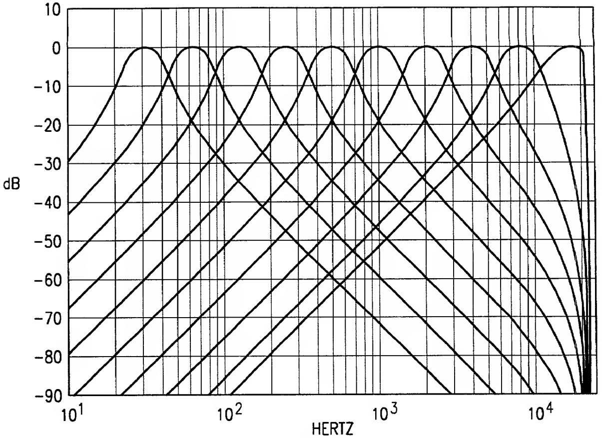

10
0
-10
-20
-30
dB
-40
-50
-60
-70
-80
-90
10^1
10^2
10^3
10^4
HERTZ

FIG. 3A

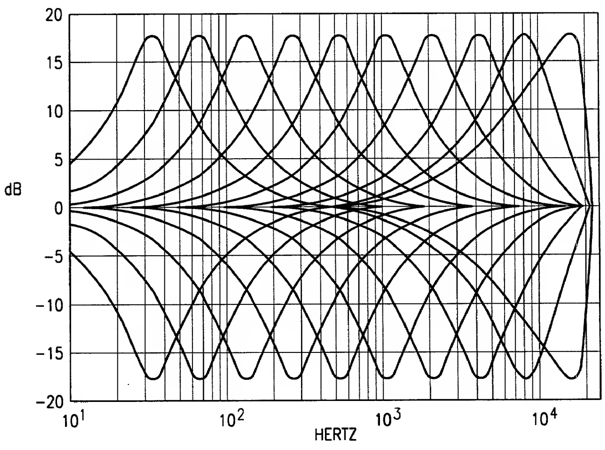
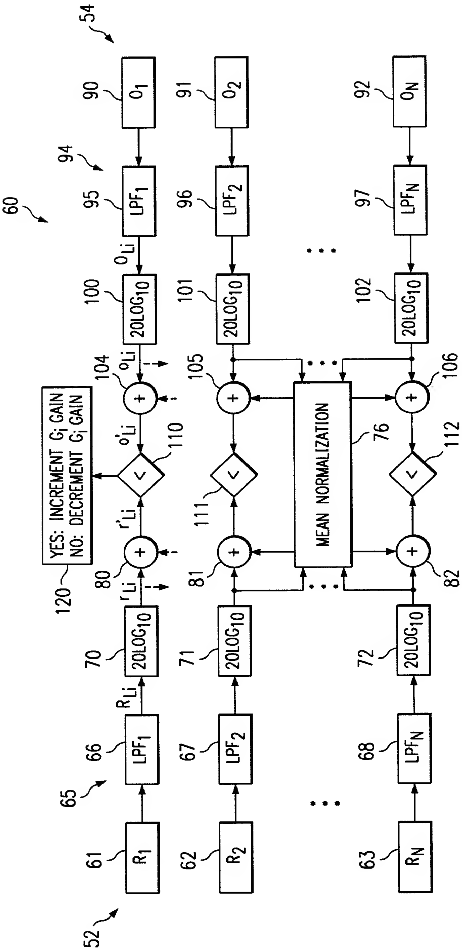

20
15
10
5
dB
0
-5
-10
-15
-20
10^1
10^2
10^3
10^4
HERTZ

FIG. 3B


YES: INCREMENT G_i GAIN
NO: DECREMENT G_i GAIN
MEAN NORMALIZATION
R_1
R_2
R_N
LPF_1
LPF_2
LPF_N
$20LOG_{10}$
o_1
o_2
o_N
R_{Li}
r_{Li}
r'_{Li}
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120

FIG. 5

APPLICATION FOR UNITED STATES PATENT

Declaration and Power of Attorney

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; that I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought, on the invention entitled as set forth below, which is described in the attached specification; that I have reviewed and understand the contents of such specification, including the claims, as amended by any amendment specifically referred to in the oath or declaration; that no application for patent or inventor's certificate on this invention has been filed by me or my legal representatives or assigns in any country foreign to the United States of America; and that I acknowledge the duty to disclose to the U.S. Patent and Trademark Office all information known to me to be material to patentability as defined in 37 C.F.R. § 1.56.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

TITLE OF INVENTION: DIGITAL SELF-ADAPTING GRAPHIC EQUALIZER AND METHOD

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TI-29300

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Date:	Dec. 9, 1999